

UNITED STATES PATENT APPLICATION

OF

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FOR

ON-WAFER ELECTROCHEMICAL DEPOSITION PLATING METROLOGY

PROCESS AND APPARATUS

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BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to electrochemical deposition (ECD) processes and systems used in the fabrication of products such as semiconductor devices, and more specifically to an on-wafer process and apparatus of such type, in which the workpiece being plated is utilized as an electrode element in the monitoring operation, thereby substantially simplifying the analytical monitoring metrology of ECD operation.

Description of the Related Art

[0002] In the field of semiconductor manufacturing, a wide variety of unit operations is employed in the fabrication sequence. These unit operations include chemical vapor deposition, photoresist patterning, development, etching and residue removal, ion implantation, etc., as well as electrochemical deposition for lay-down of copper or other metals on the semiconductor device substrate.

[0003] In ECD for copper metallization of the substrate article, an ECD bath is utilized containing an aqueous solution of copper sulfate containing sulfuric acid and chloride ions as basic inorganic components, in combination with organic constituents including accelerators (brighteners), levelers and suppressors. The rigorous control of the relative proportions of the respective ingredients in the ECD bath is critical to the achievement of satisfactory results in the rate of metal film formation and the quality of the film produced on the substrate. During the use of the plating bath solution, the plating process may be affected by additive and inorganic depletion and by organic byproduct formation. Knowing the concentration of these components of the ECD plating bath is critical to achieving a low defect yield of metalized products.

[0004] The bath chemistry therefore is conventionally maintained by periodic replacement of part or all of the plating solution in the ECD bath. The concentrations of selected components in the ECD bath may be monitored continuously or periodically, and organic and/or inorganic components may be added to the bath in response to monitoring, to maintain the composition of the bath in an effective state for the electrochemical deposition operation.

[0005] Current methods of analysis of components of the ECD plating bath include high pressure liquid chromatography (HPLC), cyclic voltametric stripping (CVS) and pulsed cyclic galvanostatic analysis (PCGA). Each of these monitoring techniques requires expensive hardware that uses valuable cleanroom space, and is susceptible to downtime resulting from monitoring system malfunction or failure, or from periodic maintenance requirements. In addition to such cost and reliability issues, none of these conventional techniques provides a true and accurate indication of the deposition process on the substrate that is being metallized.

SMMMARY OF THE INVENTION

[0006] The present invention generally relates to electrochemical deposition processes and systems used in the fabrication of products such as semiconductor devices, and more specifically to an on-wafer process and apparatus of such type.

[0007] The present invention in one aspect relates to a method of controlling copper electrochemical deposition in an electrochemical deposition system in which a wafer is contacted with an electrochemical deposition medium including at least one organic additive, wherein the electrochemical deposition medium has a plating anode in contact therewith to effect plating of copper on the wafer, and the electrochemical deposition is characterizable by at least one dependent variable correlative of efficacy of the copper electrochemical deposition, such method including:

selecting at least one dependent variable correlative of efficacy of the copper electrochemical deposition;

performing a regression analysis or multivariate calibration modeling of the copper electrochemical deposition utilizing a wafer-based independent variable to generate a dependent variable equation for each selected dependent variable correlative of efficacy of the copper electrochemical deposition;

solving the dependent variable equation for each selected dependent variable correlative of efficacy of the copper electrochemical deposition, by regression analysis, to yield a solution value for each selected dependent variable; and

modulating the copper electrochemical deposition in response to the solution value for each selected dependent variable.

[0008] The present invention in another aspect of the invention relates to an apparatus for controlling copper electrochemical deposition in an electrochemical deposition system in which a wafer is contacted with an electrochemical deposition medium including at least one organic additive, wherein the electrochemical deposition medium has a plating anode in contact therewith to effect plating of copper on the wafer, and the electrochemical deposition medium is characterizable by at least one dependent variable correlative of efficacy of the copper electrochemical deposition. The apparatus includes:

a computational module constructed and arranged to perform the following steps:

selecting at least one dependent variable correlative of efficacy of the copper electrochemical deposition;

performing a regression analysis or multivariate calibration modeling of the copper electrochemical deposition utilizing a wafer-based independent variable to generate a dependent variable equation for each selected dependent variable correlative of efficacy of the copper electrochemical deposition; and

solving the dependent variable equation for each selected dependent variable correlative of efficacy of the copper electrochemical deposition, by regression analysis, to yield a solution value for each selected dependent variable; and

means for modulating the copper electrochemical deposition in response to the solution value for each selected dependent variable.

[0009] Other aspects, features and embodiments of the present invention will be more fully apparent from the ensuing disclosure and appended claims.

Brief Description of the Drawings

[0010] FIG. 1 is a graph of plating potential E (volts) as a function of time, in seconds.

[0011] FIG. 2 is a schematic representation of an electrochemical deposition apparatus according to one embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION, AND PREFERRED EMBODIMENTS THEREOF

[0012] In the ECD process, the wafer functions as a deposition electrode due to the thin seed layer of metal thereon as deposited by chemical vapor deposition or other vapor deposition technique, with such seed layer functioning as a cathode element of the electrochemical cell in the aqueous electrolyte medium and a sacrificial anode element of the metal to be plated forming the other electrode of the electrochemical circuit. The rate of the metal deposition on the substrate is determined by the applied current, and by the concentrations of the suppressor

and accelerator species in the plating bath.

[0013] In order to achieve conformal filling of high aspect ratio features such as vias and trenches on the substrate, precise concentrations of suppressor and accelerator components, as well as chloride, are required in the ECD bath. These components must be replenished during the use of the bath to compensate for losses and/or decomposition thereof during processing. Accordingly, precise and reliable monitoring of bath components is required.

[0014] The present invention utilizes an application of fundamental modeling concepts to electrochemical signals, to achieve a simply and highly effective monitoring capability for controlling the ECD process to yield a uniform plating efficacy that is markedly superior to conventional HPLC, CVS and/or PCGA analytical techniques for monitoring ECD plating baths.

[0015] While the ensuing description is directed to an ECD system involving application of a constant plating current in a copper sulfate/sulfuric acid solution and measurement of the resulting potential to provide a signal transient as a unique signature indicative of the composition of the solution in the ECD bath, it will be recognized that the methodology and apparatus of the invention are not thus limited, but rather generally extend to and encompass the determination of analytes in fluid media. For example, although the present description is directed primarily to copper deposition, the invention is readily applicable to other ECD process applications, including deposition of silver, gold, iridium, palladium, tantalum, titanium, chromium, cobalt, tungsten, etc., as well as deposition of alloys and deposition of amalgams such as solder.

[0016] Examples of additional applications of the invention other than ECD plating of semiconductor device structures include analysis of reagents in reaction media for production of therapeutic agents such as pharmaceutical products, and biotechnology applications

involving the concentrations of specific analytes in human blood or plasma. It will therefore be appreciated that the invention is of broad application, and that the ECD system and method described hereafter is but one of a myriad of potential uses for which the invention may be employed.

[0017] The present invention in one aspect provides an apparatus and method for controlling copper electrochemical deposition in an electrochemical deposition system in which a wafer is contacted with an electrochemical deposition medium including at least one organic additive, wherein the electrochemical deposition medium has a plating anode in contact therewith to effect plating of copper on the wafer, and the electrochemical deposition medium is characterizable by at least one dependent variable correlative of efficacy of the copper electrochemical deposition.

[0018] The approach of the invention includes selecting at least one dependent variable correlative of efficacy of the copper electrochemical deposition, and then performing a regression analysis modeling or a multivariate calibration modeling of the copper electrochemical deposition utilizing a wafer-based independent variable to generate a dependent variable equation for each selected dependent variable correlative of efficacy of the copper electrochemical deposition. Next, the dependent variable equation, for each selected dependent variable correlative of efficacy of the copper electrochemical deposition, is solved by regression analysis to yield a solution value for each selected dependent variable.

[0019] The copper electrochemical deposition then may be modulated in response to the solution value for each selected dependent variable, so as to carry out the deposition operation in a highly efficient manner. Such modulation may for example including varying the output of a power supply that is arranged to supply power to the electrodes of the electrochemical deposition system. As another example, the responsive modulation of the process may include adjustment of flow control valves to vary the flow of ECD solution components to the ECD

bath chamber, so as to maintain an appropriate concentration of solution species, e.g., accelerator, suppressor, leveler, chloride anion, acid, metal salt, etc. The modulation may in like manner involve adjustment of system hardware components or change of process conditions to maximize the plating rate, plating uniformity, etc., as desired in a given application of the invention.

[0020] In an illustrative embodiment, the invention is hereafter described with reference to an ECD bath for copper plating of a semiconductor substrate, in which three organic additives, viz., the accelerator, suppressor and leveler additives are analyzed. By measuring a parametric variable such as plating voltage output as a function of time (or alternatively other parametric variables such as plating current, electrode size, or a cathode pre-conditioning pulse), the three organic additives can be determined by simple modeling approaches, as hereafter more fully described.

[0021] More complex approaches may be carried out in accordance with the invention, utilizing multivariate calibration techniques, e.g., chemometrics, for the purpose of principal component analysis and/or other curve-fitting procedures to provide process models of appropriate robustness for specific applications of the invention. Such complex approaches employ a full set of plating information (as opposed to time cuts that are employed to build a regression model), to achieve enhanced robustness for signal detection and increased signal-to-noise.

[0022] The method of the invention may be carried out with any suitable analytical equipment. For example, in application to the electrochemical deposition of copper on a semiconductor wafer, the invention may be practiced with a Sabre® xT copper electroplating tool commercially available from Novellus Systems, Inc. (San Jose, CA) or a SlimCell™ ECP copper plating tool commercially available from Applied Materials, Inc. (Santa Clara, CA), which in operation apply a constant current to a wafer in the copper plating operation. In such

operation, the voltage that develops between the wafer (cathode) and the reference electrode is indicative of the ECD plating solution composition and deposition quality. In algorithmically training on the tool of interest, the potential response of the cathode for several different plating solution permutations is measured.

[0023] By way of specific example, copper was plated on a 25 micrometer diameter platinum microelectrode. A five-factor, three-level CCD (central composite design) DOE (design of experiments) was performed. The five factors were (1) copper plating current, (2) copper nucleation voltage, (3) suppressor concentration in the ECD solution, (4) accelerator concentration in the ECD solution and (5) leveler concentration in the ECD solution. Because the plating curve voltages were measured over 50 seconds, it was decided to solve for the three unknowns by selection of three arbitrary times from all plating curves to permit modeling at 5, 10 and 15 seconds. The final model and its coefficients are shown in Table 1 below.

[0024] Table 1

Y-hat Model		50s				10s				5s			
Factor	Name	Coeff	P(2 Tail)	Tol	Active	Coeff	P(2 Tail)	Tol	Active	Coeff	P(2 Tail)	Tol	Active
Const		-0.49700	0.0000			-0.50002	0.0000			-0.50497	0.0000		
B	Platel	0.00341	0.0000	1	XXX	0.00505	0.0000	1	XXX	0.00562	0.0000	1	XXX
C	Acc	0.01884	0.0000	1	XXX	0.01924	0.0000	1	XXX	0.01965	0.0000	1	XXX
D	Lev	-0.01391	0.0000	1	XXX	-0.00700	0.0000	1	XXX	-0.00326	0.0000	1	XXX
E	Supp	-0.00226	0.0001	0.9923	XXX	-0.00202	0.0003	0.9923	XXX	-0.00406	0.0000	0.9927	XXX
CC		-0.00128	0.0518	1	XXX	-0.00815	0.0000	0.9990	XXX	0.00431	0.0000	0.9929	XXX
CD		-0.00751	0.0000	0.9990	XXX								
DD		0.00536	0.0000	0.9990	XXX	0.00151	0.0027	0.9990	XXX				
EE		0.00165	0.0032	0.9926	XXX	0.0009877	0.0614	0.9926	XXX				
R ²		0.9627				0.9565				0.9418			
Adj R ²		0.9593				0.9531				0.9380			
Std Error		0.0045				0.0043				0.0051			
F		286.7872				282.8052				245.4038			
Sig F		0.0000				0.0000				0.0000			
F _{LOF}		126.5176				89.0144				45.2024			
Sig F _{LOF}		0.0000				0.0000				0.0000			
Source		SS	df	MS		SS	df	MS		SS	df	MS	
Regression		0.0	8	0.0		0.0	7	0.0		0.0	6	0.0	
Error		0.0	89	0.0		0.0	90	0.0		0.0	91	0.0	
Error _{Pure}		0.0	73	0.0		0.0	73	0.0		0.0	73	0.0	
Error _{LOF}		0.0	16	0.0		0.0	17	0.0		0.0	18	0.0	
Total		0.0	97			0.0	97			0.0	97		

[0025] Table 1 shows the coefficient values for the five-factor analysis, as including the plating current (denoted by Factor "Const" to reflect its constant value), nucleation voltage (Factor B), accelerator concentration (Factor C), leveler concentration (Factor D) and suppressor concentration (Factor E). A Y-hat regression analysis model was selected, although any other suitable regression analysis model can be employed. The table includes goodness of fit of model (R^2) values, adjusted R^2 values, standard error, F, Sig F, lack of fit F (F_{LOF}), and lack of fit Sig F values, as well as regression and error values.

[0026] Using this model, voltage can be measured from a typical plating curve at the three times (5, 10 and 15 seconds), and additive concentrations can be determined for the three additives (suppressor concentration in the ECD solution, accelerator concentration in the ECD solution and leveler concentration in the ECD solution).

[0027] FIG. 1 is a graph of plating potential E (volts) as a function of time, in seconds for copper in sulfuric acid in the presence of three organic additives (suppressor, accelerator and leveler).

[0028] Using this data, three equations can be written with three unknowns, as shown in Table 2 below, and such equations can be solved for the concentrations of the respective additive components of the ECD solution.

[0029] Table 2

				Un-Coded Coefficients						
Run = 8: V _{plate} =	EQN #	Left Side	Constant Coefficient	ΔC	ΔD	ΔE	ΔCC	ΔCD	ΔDD	ΔEE
-0.48846	Eqn 1 (50s)	0 =	-0.01452	0.01714	-0.02622	-0.00886	-0.0008339	-0.0003409	0.00343	0.00165
-0.48773	Eqn 2 (10s)	0 =	-0.04572	0.01728	-0.01046	-0.00697	-0.0009063	0	0.0009696	0.0009877
-0.48783	Eqn 3 (5s)	0 =	-0.06210	0.01808	-0.00261	-0.00442	-0.0009607	0	0	0
Variable				C	D	E	CC	CD	DD	EE
Unique Solution				8.88	6.01	2.16				
Actual Conc.				9	3.75	1				
Difference				0.12	-1.26	-1.16				
% Deviation				1.4%	-28.8%	-73.6%				

[0030] The first three rows in Table 2 represent the coefficients in the three linear equations that allow a unique solution to the three unknown concentrations for the respective organic additives, accelerator (component C in the table), leveler (component D in the table) and suppressor (component E in the table).

[0031] As shown in Table 2, the only solution that fits all three linear equations is accelerator concentration = 8.88 ml/L, leveler concentration = 5.01 ml/L, and suppressor concentration = 2.16 ml/L.

[0032] As is shown by the actual measured values of concentration of the accelerator, leveler and suppressor components, there was some deviation for the leveler and suppressor components, but comparison of the computed and measured values demonstrated the operability and efficacy of the inventive methodology for computational determination of additive concentrations.

[0033] It therefore is clear that the plating tool itself can be the analytical instrument when the factors that affect the plating potentials are known and accounted for in the computational methodology.

[0034] The regression analysis software may be of any suitable type, including for example SAS/STAT® software (commercially available from SAS Institute, Cary, NC, USA), SSPS™ data analysis software commercially available from SSPS, Inc. (Chicago, IL, USA), Minitab® statistical analysis software commercially available from Minitab Inc. (State College, PA, USA), NCSS Stat System statistical analysis software commercially available from NCSS Statistical Software (Kaysville, UT, USA), etc.

[0035] Referring now to FIG. 2, there is schematically shown an electrochemical deposition apparatus 10 according to one embodiment of the invention.

[0036] The electrochemical deposition apparatus 10 includes an electrochemical deposition system 12 including an ECD bath. In the ECD bath, a wafer is contacted with an electrochemical deposition medium including at least one organic additive. The electrochemical deposition medium has a plating anode in contact therewith to effect plating of copper on the wafer, when a suitable voltage is imposed on the electrochemical cell circuit including the wafer as the cathode element of the circuit, and the aforementioned anode element. The electrochemical deposition carried out in the ECD system 12 is characterizable by at least one dependent variable correlative of efficacy of the copper electrochemical deposition, e.g., concentration of one or more of the organic additives, or plating current, or any other suitable variable.

[0037] The ECD system 12 in the illustrated embodiment is coupled in power transmission relationship with a power supply 32, by means of power transmission line 34. The ECD system 12 also is coupled in feed relationship with organic additive supply vessels 14, 16 and 18, by means of organic additive feed lines 20, 22 and 24 having flow control valves 26, 28 and 30 therein. The organic additive supply vessels 14, 16 and 18 may for example contain accelerator, leveler and suppressor, respectively.

[0038] The ECD system 12 is further coupled in signal processing, monitoring and control relationship with the computational module 36, which may for example include a programmable general purpose computer, dedicated microprocessor, programmable logic unit, or any other suitable computational means effective for the monitoring and control function. The computational module 36 is coupled with the ECD system 12 by means of signal transmission cable 38.

[0039] The computational module 36 also is coupled with the flow control valves 26, 28

and 30 in organic additive feed lines 20, 22 and 24 by means of signal transmission lines 44, 46 and 48, respectively.

[0040] The computational module 36 is equipped with suitable regression analysis software, such as SAS/STAT® software (commercially available from SAS Institute, Cary, NC, USA), for carrying out the regression analysis operations described hereinafter.

[0041] In operation, the ECD apparatus as shown in FIG. 2 is operated to produce a copper metalized product wafer 40, with the power supply being arranged to operatively supply power to ECD system via power transmission line 34. In the specific embodiment illustrated, the power supply is arranged to supply a constant current power signal to the ECD system 12. The organic additives in organic additive supply vessels 14, 16 and 18 are flowed in respective lines 20, 22 and 24 to the ECD system 12 for addition to the plating bath medium (not shown in FIG. 2) therein.

[0042] The voltage that develops between the wafer and the plating anode in the ECD system under the constant current conditions is indicative of the solution composition in the plating bath, and is indicative of the plating quality of the deposited metal, e.g., electroplated copper.

[0043] Prior to inception of active operation, the regression analysis software in the computational module 36 is trained on the ECD system 12 to measure the voltage response of the cathode for several different plating solution permutations. The plating voltages are measure at selected intervals, e.g., at 5, 10 and 50 seconds as described in connection with the discussion of FIG. 1 herein, or, alternatively, all points along the plating curve could be employed, since each point on the plating curve contains information reflecting the components and operation of the ECD system. Plating voltage thus is the selected dependent variable correlative of the efficacy of the copper electrochemical deposition.

[0044] The modeling operation is then conducted at the selected time intervals to establish a model and coefficients, e.g., as shown in Table 1 hereof. Thereafter, during the plating operation, the plating voltage can be monitored, and corresponding equations can be generated for the concentrations of the organic additives, accelerator, leveler and suppressor, in the supply vessels 14, 16 and 18, respectively. The regression analysis software in the computational module 36 carries out the regression analysis operations, and generates a best solution for the concentration equations for the three organic additives, thereby yielding concentration data that may be outputted, archived, transmitted, etc., as necessary or desirable in a given application of the invention. The concentration data may also include data for breakdown products of the organic additives in the ECD plating solution, since such breakdown products affect wafer yields.

[0045] By this sequence of actions, the computational module 36 performs a regression analysis modeling of the copper electrochemical deposition utilizing a wafer-based independent variable to generate a dependent variable equation for each selected dependent variable correlative of efficacy of the copper electrochemical deposition, and solves the dependent variable equation for each selected dependent variable correlative of efficacy of the copper electrochemical deposition, to yield a solution value for each selected dependent variable.

[0046] The solution value obtained by the computational module 36 then may be employed to modulate the ECD system 12 in a suitable manner, to ensure continuously optimal performance of the apparatus 10. In the specific embodiment illustrated in FIG. 2, the computational module generates an output for desired concentration of each of the organic additives (accelerator, leveler and suppressor), in the supply vessels 14, 16 and 18. The output from the computational modules is a control signal in each of signal transmission lines 44, 46 and 48, which actuates a corresponding respective flow control valve 26, 28 and 30 in respective lines 20, 22 and 24 to adjust the flow of each respective organic additive to a flow

rate that maintains the ECD system at proper concentration of the organic additives therein for achievement of high-efficiency plating operation.

[0047] The present invention thus embodies a useful methodology for monitoring composition of components in a copper plating bath. The substrate (wafer) on which copper is being deposited is used as a cathode element of an electrochemical cell including the copper source anode as a reference electrode. Constant current is applied to the electrochemical cell, and voltage is measured as a function of time.

[0048] Alternatively, if current is time-varying, plating voltage output could be measured as a function of plating current, or in other embodiments such plating voltage output could be measured as a function of electrode size (as the copper source anode is depleted), or the plating voltage output could be measured as a function of the cathode pre-conditioning pulse employed to initiate electrochemical activity.

[0049] In still other embodiments, other combinations of independent and dependant variables can be employed for the regression analysis technique, to create a mathematical model that to predict the value of a dependent variable based on values of an independent variable.

[0050] In preferred practice, the plating potential is plotted as a function of time at constant current conditions, to generate a two-dimensional graph of the type shown in FIG. 1 hereof, in which the voltage vs. time plot reflects the behavior of the bath chemistry including the organic additives whose concentrations are the desired monitored output.

[0051] Then, by selecting values of plating potential at selected times during the period of measurement, wherein the number of potential values equals the number of concentration variables, viz., three in the illustrative example (concentrations of each of the three organic

additives in the ECD bath). Then, by establishing three linear equations in three unknowns, the data analysis can be conducted to solve the equations and generate the concentration values for the respective accelerator, leveler and suppressor components of the ECD bath.

[0052] The data analysis may be conducted in a computational module associated with the ECD system, which is programmatically arranged to sample the plating bath voltage at selected intervals to generate the coefficients of the linear equations that are then solved to provide the concentration values of the additives as an output. The computational module may include a programmable general purpose computer, dedicated central processing unit (CPU), microprocessor, integrated circuitry, or other computational device or system embodying appropriate hardware, firmware and/or software, for conducting the regression analysis and solution of the simultaneous equations for the parametric unknowns. Software employed in the computational module may be of any suitable type, e.g., of a type as described hereinabove.

[0053] By utilizing a wafer-based electrode parameter as the sampled variable for regression analysis, e.g., a wafer parameter such as plating voltage output, plating current, electrode size or cathode preconditioning pulse (current or voltage), the approach of the present invention achieves a material simplification in the monitoring and control infrastructure that is required for the electrochemical deposition system, relative to prior art approaches such as HPLC, CVS and PCGS techniques. Specifically, there is no requirement of ancillary sampling chambers, additional sampling and reference electrodes, or other indirect measurement means or methods.

[0054] Additionally, and most importantly, by utilizing the wafer being plated as an electrode component of an electrochemical cell providing the sampled variable for regression analysis, the method of the invention conducts real-time monitoring reflecting conditions at the wafer, to provide an output indicative of solution composition in the plating bath. Such on-wafer ECD metrology embodies a substantial advance in the semiconductor manufacturing art,

and is a preferred embodiment of the present invention.

[0055] The regression analysis techniques used in the practice of the invention may be linear or non-linear regression techniques, depending on the nature of the sampled variable and its time-varying relationship to concentration parameters.

[0056] The approach of the invention may be applied in a wide variety of potential applications, including for example: chemical reaction monitoring and control; fermentation operations or other operations involving cell culturing in nutrient media; monitoring of dialysis treatment operations with respect to specific blood components, e.g., creatinine, urea, etc.; determining the presence or absence of specific analytes in blood or plasma during transfusions; monitoring of chemical mechanical polishing operations in the manufacture of semiconductors; controlled administration of mixed anaesthesia gases; and other industrial, biological, and environmental processes in which specific components may be critical in amount, or in which process conditions have a critical determinative effect on efficacy or acceptability of the process operation.

[0057] In application of the regression model in a specific application, the fit of data points to the best fit line or curve may be carried out by any suitable fit procedure, e.g., least squares, residual sum of squares, multiple linear regression matrix solution or other appropriate technique. The progression from best fit line or curve to determining the equation for such line or curve, and the ensuing computational correlation analysis of the multiple variables, may likewise be carried out in any suitable manner.

[0058] While the invention has been described herein with reference to specific aspects, features and embodiments, it will be recognized that the invention is not thus limited, but rather extends to and encompasses other variations, modifications and alternative embodiments. Accordingly, the invention is intended to be broadly interpreted and construed to encompass all

such other variations, modifications, and alternative embodiments, as being within the scope and spirit of the invention as hereinafter claimed.